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SOME ECONOMIC FEATURES OF PUMPING STATION OPERATION[1]

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The object of this paper is to present the results of some of the experiences of the engineering department of the St. Louis Water Division with practical improvements which have resulted in bringing about, within the last five years, a greater economy in the operation of the pumping station.

Inasmuch as the economy of such stations from a heat-saving standpoint deals directly with coal, and owing to the rapid increase in cost of coal throughout the country, it became imperative on the part of the mechanical engineers of the Department to make a thorough investigation of the heat losses existing in their respective plants with a view toward reducing such losses to the lowest possible minimum. When it is considered that the coal cost constitutes probably 40 per cent of the total pumping cost and that in the average pumping plants throughout the country not more than 10 per cent of the heat value in coal is utilized, it is easy to see that the more economical use of coal is highly profitable.

[1] Read before the Montreal Convention, June 22, 1920. Discussion is requested and should be sent to the Editor.

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In passing it would be well to mention the St. Louis experience in storing coal. It was found that practically all grades of bituminous coal can be stored for an indefinite period without any material loss in its heat value, if proper precautions are taken in storing it. The Water Division of the city is provided with storage capacity of 15,400 tons which will maintain a supply sufficient to last over a period of 60 days. Notwithstanding the fact that the city is in close proximity to the Illinois coal fields, the wisdom on the part of the Department of Public Utilities in maintaining this liberal supply for emergency use has manifested itself on several occasions since the beginning of the War. The coal stored is known as 6 inch screened lump and it is piled 16 to 18 feet high in sheds, figures 1 to 4.

Heat value determinations have been made on this coal after having been in storage for a period of 10 years, the results of which show no appreciable heat loss due to storing. Naturally coal loses some of its moisture, and this loss tends to compensate for the heat loss due to some of the volatile gases being set free. The Water Division does not attempt to store Illinois screenings for any length of time. It has, however, stored such screenings, containing about 45 per cent by weight of duff, for one year. By duff is meant coal that will pass through a screen having circular perforations $\frac{1}{4}$ inch in diameter. This coal showed no signs of heating and was placed in a pile about 6 feet high in the open air with no protection from rain or snow. In general, it has been the experience at St. Louis that all bituminous coal free from fines or duff can be stored for an indefinite period without appreciable heat loss, it being preferable to store sized lump coal, placing it so as to minimize breakage.

According to the St. Louis Water Division's experience, the chain grate type of stoker is best suited for burning the low-grade clinkering coal, such as is found in the Illinois coal fields within a radius of 25 miles from St. Louis. This type of stoker is capable of meeting any peak load up to 100 per cent above normal boiler rating, it is simple in construction, easy to repair, it can be operated under all load conditions with natural draft, thereby greatly simplifying the boiler room equipment, and can be operated efficiently on light loads and overloads. Its first cost is about half that of the forced draft underfeed type. A ratio of 1 square foot of grate surface to 48 square feet of boiler heating surface has given the best results, considering the loads and coals. The coal is 2 inch Southern Illinois screenings, having an average heat value of 10,300 B. t. u. with from 20 to 25 per cent ash.

Fig. 1. Emergency Coal Storage Shed, Chain of Rocks Station

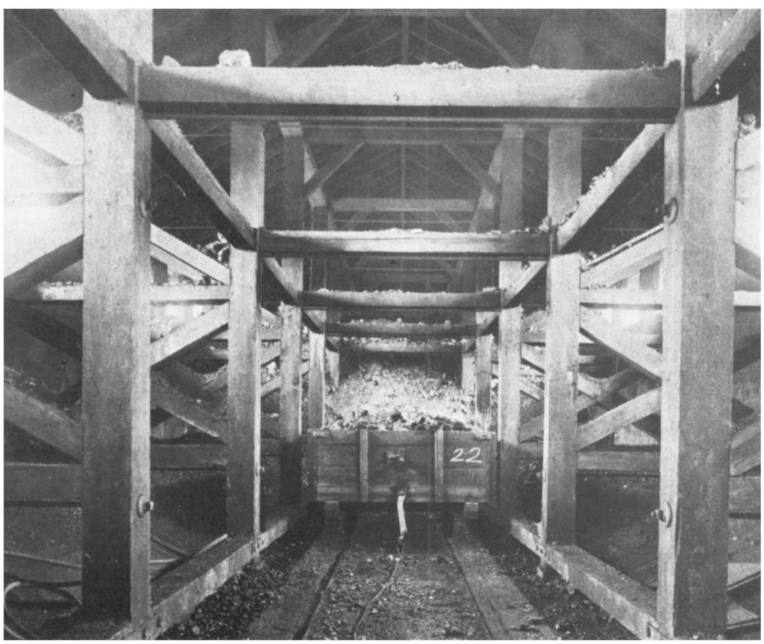

Fig. 2. Interior of Coal Storage Shed, Chain of Rocks Station

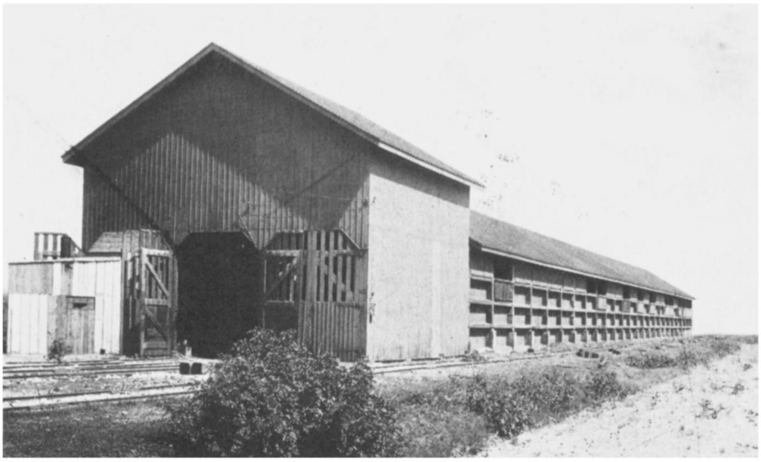

Fig. 3. Emergency Coal Storage Shed, Baden Station

Fig. 4. Emergency Coal Storage Shed, Bissell's Point Station

In addition to the proper size grate, experience at St. Louis shows that a properly designed furnace arch and a combustion chamber with sufficient volume to allow complete combustion will add greatly to the efficiency and capacity of the boilers. The first chain grate stokers used by the Water Division were installed at the Chain of Rocks plant in 1914. The stokers were placed under six National water-tube boilers, each of 360 horsepower, and two O'Brien water-tube boilers, each of 250 horsepower capacity. The boilers were set 7 feet from the floor, and the arches were set 11 inches from the grate at the front, and 22 inches from the grate at the rear, the arch being 6 feet 5 inches long. The original arch was set according to the design of the stoker contractor. The boilers were arranged with horizontal baffles, the lower baffle being placed on the second row of tubes. The average boiler efficiency under operating conditions with this setting was approximately 58 per cent and it was difficult to obtain an overload of 25 per cent.

Investigations were started at this station with a view to increasing the boiler efficiency and capacity. It was found that a stoker arch, to function properly, should be set high enough over the grate to allow the volatile gases to be distilled off without being crowded under the arch; also that the shape of the arch should be such as to allow the heat from the bridge wall to be focused on the coal as it enters the furnace. This latter condition is necessary to start combustion in as short a time after the coal leaves the feed gate as possible, so that every available foot of grate surface is utilized for burning coal. By referring to figure 5, which shows the original arch, it will be apparent that from the standpoint of obtaining a large liberating volume under the arch and an efficient shape of the roof, so as to obtain the maximum benefits of heat reflection coming from the bridge wall, this arch did not function properly. Referring to the lines bearing arrows indicating heat rays, it will be observed that this arch does not permit a concentration of heat at a point where a maximum concentration is desired, namely, at the point of ignition. These objectionable features have been overcome by the new design of arch shown in figure 6.

In this setting, the distance from the floor to the front water leg remains 7 feet, being determined by the original setting of the boiler. The arches are set 12 inches from the grate at the front end, rise rapidly to a hip, and are 36 inches high at the rear. The length of the arch is 6½ feet. This arch has a better concentration of heat

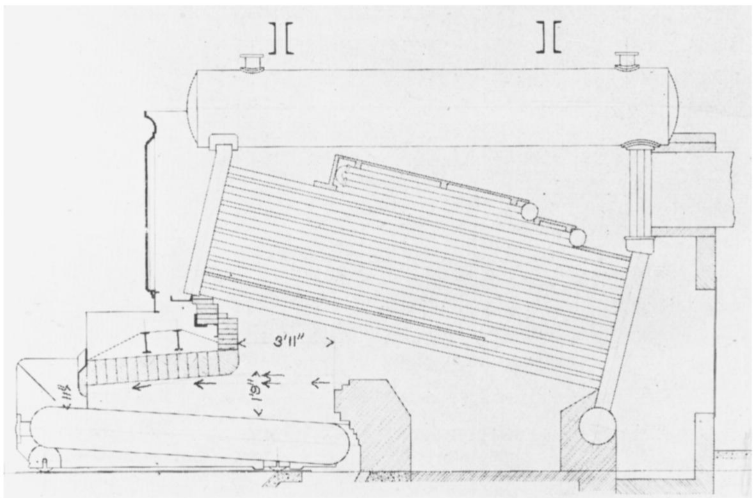

FIG. 5. ORIGINAL BOILER SETTING, CHAIN OF ROCKS

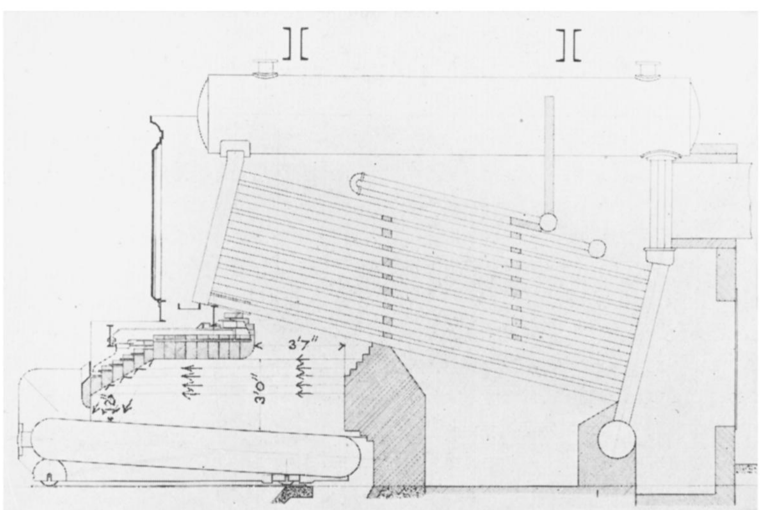

FIG. 6. IMPROVED BOILER SETTING, CHAIN OF ROCKS

rays near the feed gate, the rays being reflected from the bridge wall, than the one shown in figure 5, due to obtaining an arch contour which approximates the curve of a parabola, in which curve all reflected heat rays concentrate at the focus. To illustrate, figure 7 shows a parabolic curve superimposed on the improved arch.

Comparative tests made before and after the change in the arch shape resulted in the following:

With the old type arch, on a capacity test run by the stoker contractor, an evaporation of 15,770 pounds of steam per hour was maintained for ten hours. With the new style arch an evaporation of 17,140 pounds of steam per hour was maintained for five hours. The former represents an overload of 38 per cent while the latter represents an overload of 60 per cent. At the same time the average boiler efficiency was increased from 58 per cent to 63 per cent, or a gain in efficiency of approximately 9 per cent. After all boilers have been equipped with the new arch, it is estimated that the saving in annual coal cost will amount to about $5000 at this station.

A similar improvement in capacity and efficiency was made at the Bissell's Point Station. The boilers at this station are set with the front water leg 6½ feet above the floor line. The original arches were sprung transversely across the grate 9 inches above the grate at the hip, rising to 18 inches above the grate at the center. Longitudinally the arch was parallel to the grate. This type of arch, that is, in respect to the low height above the grate, was the common practice among chain grate stoker builders up to within but a few years past. The arch was removed and replaced with a new type of flat arch, which is 12 to 13 inches above the grate at the feed gate and rises straight, without a hip, to 30 inches above the grate at the rear end. The length is 7 feet. It was not possible to construct a hipped arch at this station because of the limitation of the low setting. However, a good saving was effected for the reason that prior to the change in arch design, it was only possible to burn crushed egg or lump coal at this station, due to the low arches, which did not effect a proper ignition with the lower grades of screenings. The new arch makes it possible to burn the lower grades of screenings successfully, and obtain the same evaporation per pound of coal with screenings as with the crushed egg or lump coals, thereby resulting in a saving in the price of coal of about 18 per cent. This 18 per cent saving in the price of coal, when applied to last year's coal cost at this station, amounts to an annual saving in coal cost of about $10,000. Also,

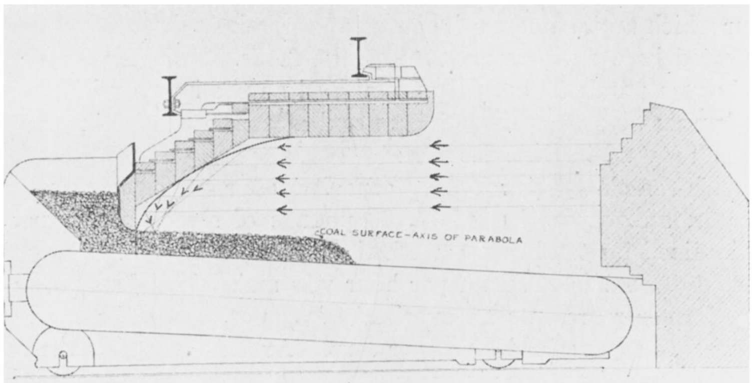

FIG. 7. APPROXIMATION OF NEW ARCH TO PARABOLIC CURVE

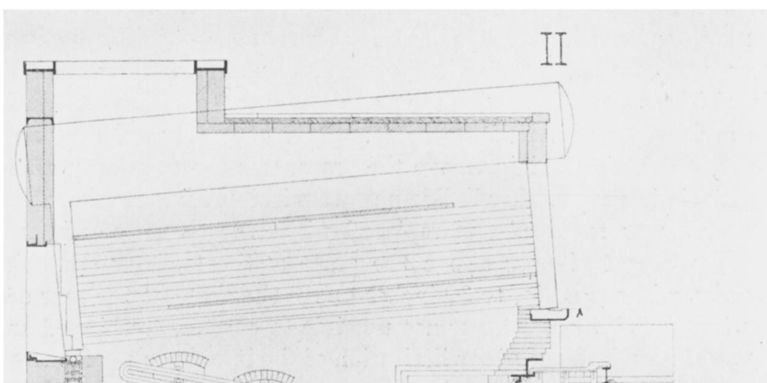

FIG. 8. NEW BOILER SETTING, BADEN STATION

after all the boilers at this station were equipped with the new type arch, the average overall rating of the boiler room rose from 90 to 115 per cent, even with the use of a lower grade of coal.

Although it was realized after the new arch was designed, that the setting was not perfect, the boilers being too low, yet even with the low setting the arch has given the improvement in capacity and efficiency mentioned above, permitting one boiler to be taken off the line.

The results of experiences with the two installations, led to the adoption in the installation of new boilers at the Baden plant, of a setting which is believed to eliminate all objectionable features found by previous experience. Figure 8 shows a cross section through this setting. The arch is similar to that of the new arch for the Chain of Rocks Station; the distance at the feed gate above the grate is 10 inches, rising rapidly to a hip, and is 34 inches above the grate at the rear. The length of the arch is 7 feet. The height of the front water leg above the floor is 9 feet, this height providing a larger combustion chamber than in the previous settings, thereby obtaining a more thorough mixing of the gases and oxygen, and providing a relatively longer gas travel, all of which are necessary for the efficient burning of coal at high rates of combustion. The evaporation at this station averages $6\frac{1}{2}$ pounds of water per pound of coal at a boiler efficiency of 66 per cent. Comparing this performance with that of the other stations, when the old type of settings prevailed, shows a saving of about 13.8 per cent in coal.

As has been previously stated, the over-all boiler efficiency of the other two stations is 63 per cent with the improved arch, while that at the Baden station, with practically the same style arch as was adopted at the other stations, shows an over-all boiler efficiency of 66 per cent. This increase of 3 per cent in efficiency, or a gain of 4.8 per cent, may be attributed to the higher boiler setting, namely 9 feet instead of 7 feet, which prevails at the other two stations. In other words, by setting the boilers 2 feet higher at the Baden station, a gain of 4.8 per cent in over-all boiler efficiency has been made. This gain, when computed on the annual cost of coal at this station, amounts to $3,000 annually.

An operating over-all boiler efficiency of 66 per cent, using Southern Illinois screenings of 10,300 B. t. u. per pound and meeting a variable daily load, may be considered as good as can be expected from this type of boiler room installation.

The actual cost of rebuilding the arches at the Chain of Rocks and Bissell's Point Stations amounted to about $300 per arch or a total of $4200, while the saving in coal effected due to these changes amounts to approximately $15,000 per year. The entire work of rebuilding the arches was paid for in $3\frac{1}{2}$ months.

The above mentioned gains are principally due to the improvement in furnace design, but part of the saving in coal must be credited to improvements made in our boiler baffling.

Boiler baffling should be so placed as to force the gases into contact with all parts of the tube bank. In the older Heine type of settings of the stations, the lower baffle was made of box tile on the lower row of tubes and the upper baffle was 13 tubes above on the top row of tubes. The opening in the lower baffle was in some cases as much as 60 inches from the rear water leg. The path of the gases in this type of boiler was diagonally upward through the tubes leaving the rear water leg and the tube ends near it untouched by the hottest gases, and leaving a dead triangular pocket at the bottom of the front water leg.

By eliminating the box tile on the lower row of tubes and placing a specially designed tile on the third row of tubes, and also reducing the opening in the lower baffle from 60 to 42 inches, the flue temperature was reduced from an average of 650°F. to an average of 550°F.

It will be apparent from figure 8 that the velocity of the gases is higher through the tubes, thereby reducing the insulating effect of the film of idle gas around the tubes and resulting in a better heat absorption. It will also be apparent that the bottom rows of tubes are now exposed to the radiant heat of the flames; thus by raising the baffle tile onto the third row of tubes, the gases are crowded into more intimate contact with the tubes, dead pockets in the passes are destroyed, and the lower row of tubes, by absorbing the radiant heat of the flames, tends to lower the temperature of the surrounding walls of the combustion chamber, which in turn tends to increase the life of the setting.

When it is remembered that roughly there is a gain of 1 per cent in boiler efficiency for every 25°F. reduction in flue temperature, it will be seen that there was an approximate gain of 4 per cent in efficiency for the 100°F. drop just mentioned, a gain effected by merely placing the boiler baffling in a better location and at a negligibly small cost.

Simultaneously with the installation of chain grate stokers, superheaters were installed in the boiler settings, as shown in figure 9.

For determining the size of superheaters, accurate gas temperatures were taken at the place where the superheaters were to be located, and steam, load, and firing conditions noted simultaneously as an aid to the manufacturer of the superheater in arriving at its proper size.

In the case of horizontally baffled boilers, the superheaters are located in the combustion chambers back of the bridge wall, and in the vertically baffled boilers, the superheaters are located under the shell between the first and second pass. Although the location behind the bridge wall is apparently a severe location, yet it has been the experience at St. Louis that if the superheaters are not within the direct path of the flame, they show no effects of the heat and promise a long life. The advantages of the location in the combustion chambers are a smaller superheater and greater accessibility.

The use of superheated steam at all of the plants has proved to be one of the greatest factors in increasing the efficiency of the engine rooms.

Superheated steam in the cylinder of a steam engine transfers heat to the cylinder walls, but instead of condensation occurring on contact, as with saturated steam, the superheat must first be withdrawn. Superheated steam maintains a higher cylinder wall temperature and if superheating is carried far enough, condensation can be delayed until after cut-off and even until expansion is partly completed. Also the specific volume of superheated steam is greater than that of saturated steam and this increase in specific volume, the pressure being constant, diminishes the weight of steam to the engine, and has an influence on the economy gain, as has also the lower thermal conductivity of superheated in comparison with saturated steam.

The Water Division has made tests on the effects of superheated steam on triple expansion and on compound pumping engines.

The triple expansion engines, which pump against a head of 85 to 125 pounds pressure and have capacities of 15,000,000 to 20,000,000 gallons daily, showed the saving for various degrees of superheat given in figure 10. The steam saving for 100° superheat amounted to 12.1 per cent, while the saving in coal amounted to 7.5 per cent.

The low-service compound pumping engines, which pump against a maximum head of 65 feet or about 28 pounds pressure, and have a nominal capacity of 30,000,000 gallons daily, showed the saving for various degrees of superheat given in figure 10. The steam sav-

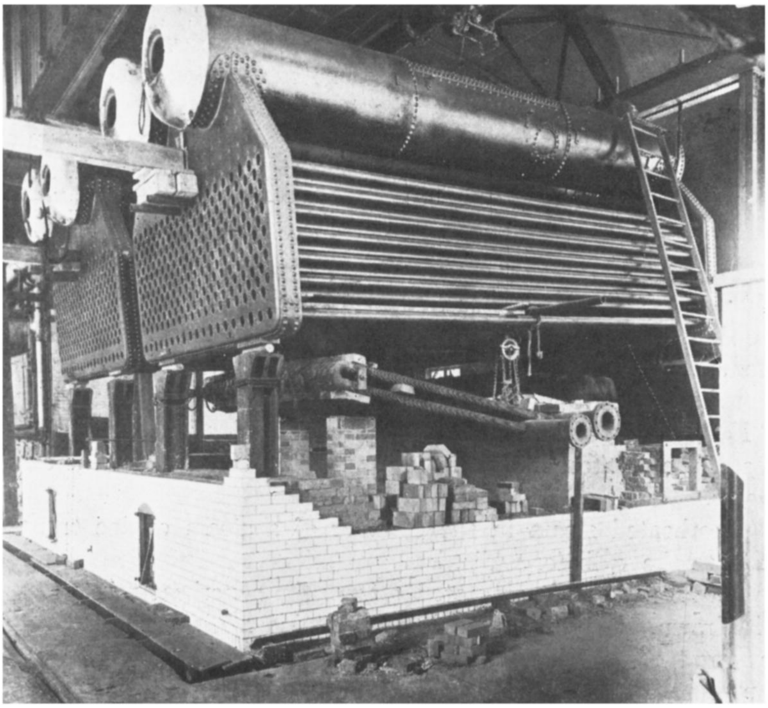

Fig. 9. New Boiler Setting, Baden Station

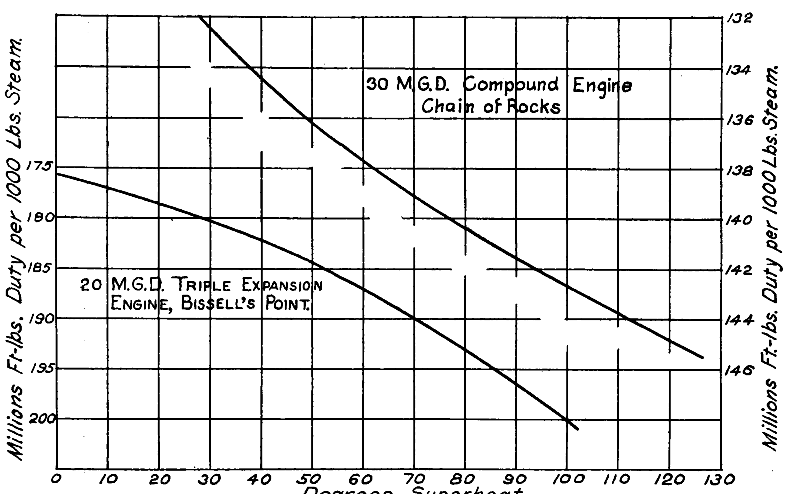

Fig. 10. Effect of Superheat on Compound and Triple Expansion Pumping Engines

ing for 100° superheat amounted to 17.3 per cent while the saving in coal amounted to 13.2 per cent.

The saving in coal due to the introduction of superheated steam into the Chain of Rocks stations has been sufficient to pay for the superheaters in about 3½ years. The life of a superheater, when the elements are not exposed to the direct flame, should be equal to the life of the boilers.

It is commonly accepted that the degree of superheat for the usual equipment of engines and pumps is limited by a total temperature of 500°F., especially when using cast-iron fittings. The Water Division has resorted to the use of cast steel fittings and valves on all new pipe work. The new piping was not installed solely with the idea in view of meeting the total temperatures of the superheated steam which it was intended to use, but also to insure more reliable service in all of the pipe lines than cast iron fittings and valves would give. However, in one of the plants the original extra heavy cast iron fittings made by a reputable manufacturer have given excellent service with a total temperature of as high as 500°F. These fittings have been in service some five years under superheated steam conditions without showing any apparent signs of weakness.

While speaking of steam piping, the following quotations in favor of superheat are given:

> Due to the absence of moisture, superheated steam offers less friction passing through pipes than saturated steam, therefore, the speed of travel can be higher and the piping, fittings and valves smaller. When piping is designed especially for superheated steam, the reduction in size will go far towards paying for the superheaters. Where it (superheated steam) is turned into an existing system of piping, the radiation may be somewhat greater than if the piping were of proper size, but the reduction in pressure would be less. The actual radiation from superheated steam, under similar conditions, is less than it is with saturated steam, because, even though the temperature is higher, its low conductivity makes it lose heat less rapidly. Besides, the pipes are not so wet and hence have less conductivity. Depending on the steam speed and the pipe protection, superheated steam is figured to lose 1° of superheat in from 6 to 10 feet of travel.

Reverting again to the tests made on the compound pumping engine to determine the effect of superheat. The pumping engine, when it was originally installed 25 years ago, developed a duty of 118,000,000 foot-pounds per 1000 pounds of saturated steam, no superheat being used at this time. The pumping engines at this station were all bought on the bonus and forfeiture basis, which naturally led the contractor to make every effort toward obtaining

the very highest duty possible. The Water Division, however, in running the duty tests with variable degrees of superheat, made no attempt whatever to increase the economy of the pumping unit before the test was run, by increasing the vacuum, repacking the plungers, renewing pump valves, inspecting valves and pistons, and so forth. In other words, the test was run on a pump operating under every day plant conditions and even with a superheat of only 28°, which is the lowest obtainable, the pump developed a duty of 132,000,000 foot-pounds per 1000 pounds of steam, which is a saving of 11.9 per cent in steam consumption over that of the original duty test with saturated steam. This is a very creditable showing for a pump that has been in service for 25 years.

As previously mentioned a better saving by the use of superheated steam was expected in compound low-service pumping engines than in the high-service triple expansion engines, for the reason that a compound pumping engine of the usual cylinder proportions is not as economical as a triple expansion pumping engine, due to a greater heat drop in each cylinder causing a greater cylinder condensation. As superheated steam specifically functions to prevent cylinder condensation, it follows that its greatest virtue will be manifested in the less economical engine.

There seems to be, to the author's knowledge, a prevailing impression in a great many water works plants, that the use of superheated steam with its consequent economies is offset by difficulties with lubrication. This contention is not borne out by the experience of this Division.

In lubricating engines using superheated steam, the only parts which actually come into continuous contact with superheated steam are the inlet valves on the high-pressure cylinder, for all other parts of the engine beyond this point, cylinder and piston, are at a mean temperature lower than the steam temperature entering, due to the fact that steam with even 100° superheat becomes saturated by the time the piston travels to the point of cut-off in the high pressure cylinder. The lubricating problems were found to be no more difficult with superheated steam than with saturated steam. The cylinder oil possesses the following characteristics, to quote from the specifications:

Cylinder oil shall be a compounded oil of 2 per cent pure acidless oil, and 98 per cent pure filtered mineral oil. It must be free from dirt, grit, lumps and specks; transparent amber in thin film; bright ruby through neck of four-ounce bottle; translucent greenish by reflected light. It must satisfactorily pass the following tests:

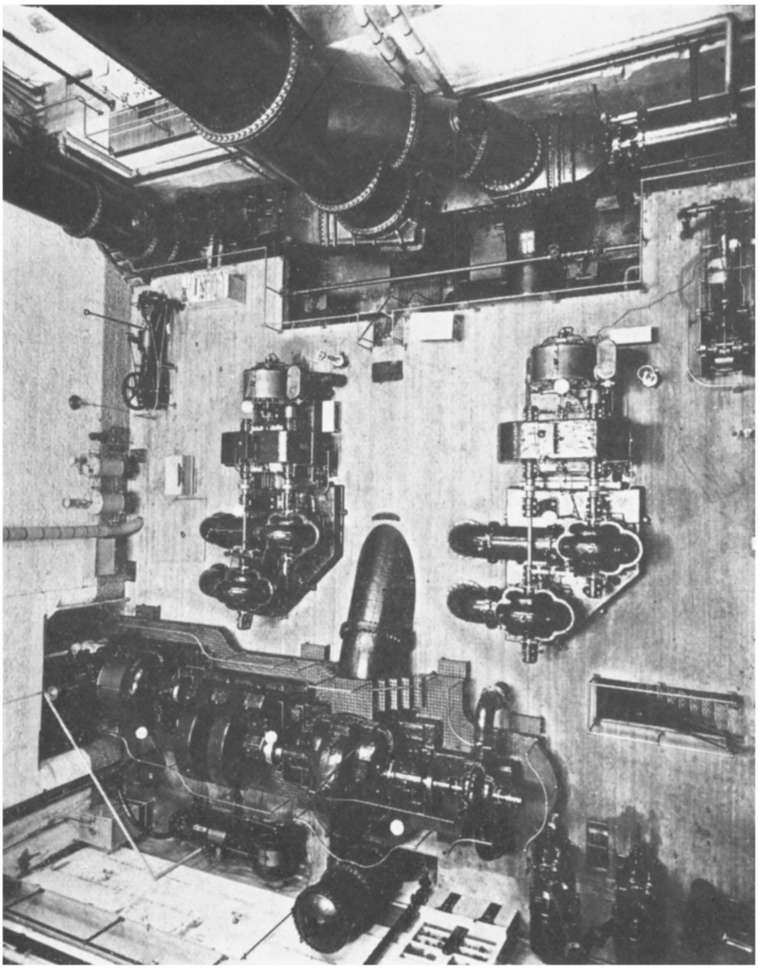

Fig. 11. Middle Pit, Chain of Rocks Station, with New 100,000,000-Gallon Steam-Turbine-Driven Centrifugal Pump and Two 35,000,000-Gallon Similar Units

Specific gravity.—26° to 28° Baumé at 60° Fahr.

Flash point.—Must not flash below 540° Fahr.

Burning point.—Must not burn below 600° Fahr.

Viscosity.—Must not be less than 3.75 (Engler) at 212° Fahr.

Cold test.—Must flow readily at 50° Fahr.

Water.—Must not froth or bump when heated in flash cup.

Tarry and suspended matter.—5 ccm. of this oil shaken with 95 ccm. of 88° petroleum ether in a glass stoppered graduate must show no precipitation of tarry and suspended matter.

Volatility.—Heated for two hours at a temperature of 400° Fahr. this oil must not show a loss of more than 5 per cent by weight.

Saponification.—When oil is treated with alcoholic potash it must show a presence of 2 per cent tallow oil.

For a short period, a straight mineral oil with no tallow was used as cylinder oil with superheated steam, but was soon found to be unsatisfactory. It was found that the compounding with tallow was necessary.

The steam-turbine driven pumps are installed in the same station with the low-service compound pumping engines previously referred to. Two of these are of the single-stage centrifugal type, each of a nominal capacity of 35,000,000 gallons of water a day. They were installed in 1913 and have been in active service ever since. The test duty of these pumps, at a head of 65 feet was 100,000,000 foot-pounds per 1000 pounds of saturated steam.

A recent test run under the same pumping conditions, but with 124° of superheat instead of saturated steam, showed a duty of 115,000,000 foot-pounds per 1000 pounds of steam, an increase in duty of 15 per cent. The physical condition of the pump may be said to have been the same during both trials for the reason that the unit had just been overhauled, a new steam wheel installed, nozzles rebored and new pump impeller wearing rings installed, when the test with superheated steam was made.

On the same turbine-driven centrifugal pump, comparative tests were made to determine the difference in duty, with the same superheat of 82° and the same vacuum, before and after the pump was overhauled as just described. The duty before overhauling was 93,500,000 foot-pounds per 1000 pounds of steam. The duty after overhauling was 106,000,000 foot-pounds per 1000 pounds of steam, showing a saving of 13.3 per cent, due entirely to overhauling.

It might be well to mention that the pumps at the low service station are subject to abnormal wear due to their pumping raw river water containing a great deal of sand in suspension.